

Vapor Intrusion Risk Pathway: Overview, Methods & Practical Strategies

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This presentation is a condensed version of the vapor intrusion training that Dr. Hartman has been presenting to Federal & State regulatory agencies, DOD facilities, consulting groups, and stakeholders around the country. As of May 2007, this training has been given to over 30 State Regulatory agencies, including ASTSWMO and the State Coalition of Dry Cleaners. Training has also been given to many PRPs such as the major oil companies, Armed Services, & EPRI.

Lecture notes are at the bottom of each slide so that if played out as a hard-copy, the presentation can be a useful reference document.

Seminar Overview

- Overview of Vapor Intrusion
- A Few Basics
- Very Brief Review of EPA Guidance
- Overview of Assessment Methods
- Soil Gas Sampling/Analytical Issues
- Practical Strategies for Assessing the Pathway
- Recent Case Histories

This presentation consists of an overview of the vapor intrusion risk pathway, a few basic principals required to perform vapor intrusion assessments, a quick review of the newest Federal and other vapor intrusion guidances, an overview of assessment methods, soil gas sampling and analysis issues, practical strategies to employ when assessing the pathway, and if time allows some case histories.

Evidence
of
residual
LNAPL ?

National
Enquirer

Town is a time bomb!

It's sitting on sea of gasoline — and could blow up at any minute

It's a town that could explode at any minute!

The 1,700 residents of Hartford, Ill., are sitting on a ticking time bomb — because the whole town rests on an underground pool of close to four MILLION gallons of gasoline leaked from refinery pipes.

At any moment, a lit match or even a spark could ignite the ever-present gasoline fumes. The village has even put up street signs warning drivers not to leave their car motors running.

It's no empty threat — fires have already erupted at two homes when gas fumes ignited.

A year ago, the house that Harold and Norma Settles had built and lived in for 25 years caught fire and exploded, destroying the home and a lifetime of possessions.

"According to the fire department, the gas fumes entered the basement and were ignited by our furnace," said Norma, who now lives with her husband in a neighboring town, Wood River.

"It was a devastating sight. All the things I had saved for decades were gone. My husband and I are retired and had planned to live there the rest of our lives. But there was nothing left."

Everyone in town lives with the terror of the gas fumes, but it's especially frightening to Police Officer Doug Neal and his wife Nora, whose basement caught fire last May.

"Fumes in the basement were ignited by the water heater," Nora said.

"That set the basement walls on fire. We were able to extinguish the flames quickly, but no matter what you do, you live in fear."

Edwin Gallagher, a real estate broker, investigated his client's house for several days.

— Even the dirt burns

DEADLY DANGER. This sample of the town's soil is so lethal it bursts into flames when lit!

POWDER KEG. The town of Hartford, Ill., (above) is soaking in gasoline as Edwin Gallagher (below) shows — he got this jar full from a well.

partment of Public Health, says the gas fumes "are a terrible threat to public health" that can cause irritation of the eyes, nose and throat; headaches; nausea, and breathing difficulties.

Cindy Filson, a geologist with the Illinois Environmental Protection Agency, said the problem is especially bad during heavy rains when the water table rises, pushing the gasoline closer to the surface and increasing the fumes.

She added: "There's always the possibility that a large building could explode and cause a major fire, injuring or killing innocent citizens."

state hopes to have a plan to put into action. Yet many people continue to live in fear."

Vapor intrusion cases making headlines around the country – even the National Enquirer!

The state DEC says it used faulty testing standards to determine if some toxins buried in the ground are dangerous. The agency says these 14 formerly contaminated sites in NYC may still be exposing nearby residents to serious health risks.

- 6 sites are near or underneath homes
- 2 sites are near or underneath schools
- 2 sites have already shown vapor intrusion problems
- 1 site is underneath

of most concern are TCE, a degreaser, and PCE, a dry-cleaning chemical, both of which are colorless and odorless carcinogens.

EXCLUSIVE

By SAM SMITH

In a stunning misadventure, 422 contaminated suits across the state — including 14 in the city — designed solely by environmental officials are now feared to be leaching deadly chemicals into schools, homes and other buildings nearby.

The state Department of

The state Department of Environmental Conservation is now launching mammoth effort to retest the sites, re-clean them if necessary, and inform residents if toxins have breached their homes or schools.

"The models applied in the past under-predicted the potential that [toxic] could emerge and get into indoor spaces," said DEH Commissioner for Air and Waste Management C. Johnson,

In addition, new toxic information has shown two chemicals — trichloroethene, or TCE, and tetrachloroethene, or PCE

The DEC wants to relocate 421 sites — including 18 in the city — because of their concentration of VCE and PCE; or their proximity to schools and homes.

The agency won't stop when the air and soil testing will begin but has said it may call on owners of the contaminated sites to pay for the retesting and additional costly cleanup — even though they were told their cleanup work

"They are opening a big can of worms," said James Perkonis, former chair of the environmental law section of the state Bar Association, who said that

The 14 city sites include

On 92nd Street in Oyster Park, Queens, PS46 sits across the street from a former manufacturer of airplane parts that spilled

Anti-Human Tumor 2
Anti-Jackie
Mendez fears for
Johnny and
Daddy, whose PS
65 is near the
site of a
carcinogenic J
Degraded Hall.

The area was cleaned and tumbled, but as the school has learned, there could still be toxins rising in the school.

"That's very scary," Jackie Mendez, who is picking up her niece for her. "The testing should be done quickly so it doesn't hurt the kids."

At Holy Child Church on Staten Island, which runs a preschool and also has another preschool site with TCE and other chemical concerns nearby, more than 100

"I've always been worried about it," said Anna Hernandez, who also lives next to the site. "But I did some work on it and said everything was fine."

The miscalculation became apparent at in Colorado five years later, where, based on air modeling, officials believed there was no of vapor intrusion. It is the field proved

The issue hit close home in 2009 in a *Washington Post* *Indecent*, where the author similarly found the ruling was wrong at

The DEC is the state environmental agency in the nation, with a mission to

Percy and his bought their house



Glendale, Queens, and a half apx.
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PEAC — a carboxylic acid chemical — is found in the ground and in the home.

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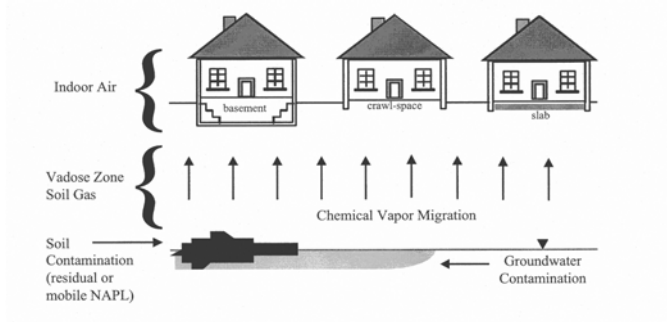
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What Is Vapor Intrusion?



Key Assumptions:

- Risk level (1 in 10,000? 100,000? 1,000,000?)
- Toxicity of Compounds
- Exposure Factors (time, rates, ventilation)

Vapor intrusion refers to the upward migration of contaminants in the vapor phase from groundwater, soil, or soil gas contamination sources.

Key assumptions to the risk determination are the risk level, the toxicity of the contaminant, and the exposure factors. These parameters are often much more important than model parameters such as soil porosity and pressure gradients.

The Da Vapor Code

(Newest Box-Office Blockbuster)

- AEHS 2007, 2006, 2005, 2004
- AWMA Conf (9/07, 9/06, 1/06)
- Workgroups Everywhere:
ASTM, ITRC, EPA-OSWR, API
- EPA Seminars (2003 & 2004)
- Requests for Training from >30 States

Vapor intrusion is the hot topic right now and, in movie lore, is a box-office blockbuster. Recent conferences on the topic have all been heavily attended and numerous workgroups are currently drafting policy. Many state agencies and EPA regions are requesting training on the topic.

ITRC Survey Results

- 39 of 43 states say vapor intrusion is a current concern being actively addressed
- VI concerns in every program (RCRA, FUDs, CERCLA, brownfields, UST, dry-cleaning,
- Most preferred methods for evaluating vapor intrusion: shallow soil gas/subslab sampling followed by indoor air measurements
- 9 states allow for biodegradation of petroleum hydrocarbons

Interstate Technology Research Council (ITRC) conducted a survey of all States re vapor intrusion in late 2004. The results showed that nearly all States are worried about this pathway in most of their programs and that soil gas measurements are preferred over indoor air measurements.

Why Do You Care About VI?

(Risk Often More Perceived Than Real)

- Health & Safety of Occupants
- EPA Draft VI Guidance Exists
- CA-EPA/DTSC: Guidance Exists
- Individual Counties: SRWQCB
- ASTM New Phase 1 Standard
- Attorneys & Citizen Groups

In some cases, there is a real threat to occupants.

But in the majority of cases, the risk to occupants is exaggerated, hence the perception is greater than the real risk. Nevertheless, you need to worry about it because the EPA has identified it as a risk pathway, numerous states have their own guidance or policies, and citizen groups and of course, attorneys are making it an issue.



Which one is the famous attorney and who is it?

When to Worry About VI?

- If VOC Contamination & Structures Exist:
 - Laterally within 100' (NH: 30' for HC)
 - Vertically Within 100' (NH: 15' for HC)
 - NY: No Limits!!!
- Complaining Occupants
- Structures With Odors, Wet Basements/floors
- Sites With Contamination & Future Use**
- Even Animals, Fruits, Vegetables

The EPA guidance uses the distance criteria listed above to screen sites needing to assess the pathway. At sites with existing contamination but no current buildings, the pathway will need to be assessed when development is proposed. Attorneys and community activist groups can expand these criteria beyond the EPA limits. In some recent cases, concern about the safety of burrowing animals, and fruits & vegetables has been the reason to assess the vapor intrusion pathway.

What Compounds?

- VOCs:
 - Hydrocarbons (benzene, aliphatics)
 - Chlorinated HCs (TCE, TCA, PCE, VC)
 - Methane, Dioxane, Oxygenates
- Semi-VOCs:
 - Naphthalene & PAHs
 - PCBs & Pesticides
 - Pb

The list of compounds that are in the EPA VI guidance and some State guidances include VOCs and semi-VOCs. Naphthalene is particularly problematic because existing GC/MS methods (TO-15 & 8260) have problems reaching low levels. The semi-VOCs are problematic because the risk-based screening levels (RBSL) are typically very low (eg., for PCBs & Pb the RBSL is 10 to 100 times lower than benzene) and this creates sampling and analytical headaches.

What Types of Sites?

- Petroleum Hydrocarbons
 - Service Stations, USTs, Pipelines
 - Oil Furnaces (naphthalene)
- Chlorinated Hydrocarbons
 - Vapor Degreasers (TCE, TCA)
 - Dry Cleaners (PCE, DCE)
 - Circuit Boards (VC, TCE, CCl₄)
- Semi-Volatiles
 - MGP Sites (PAHs)
 - Electrical Power (PCBs)

Common sites that may be susceptible for vapor intrusion problems are any locations containing VOCs. Most commonly, USTs, tanks, piping, and refueling operations associated with petroleum hydrocarbons. In the colder climates, homes with internal oil tanks are potential candidates. Common sources for chlorinated compounds are dry cleaners (PCE), engine & parts cleaning areas with vapor degreasers (TCE, TCA) and any circuit board manufacturing facility. Semi-volatile sites include MGP sites and any sites with electrical power facilities. Contamination may exist in the soil, groundwater, or as vapor clouds. Structures overlying or near these sources may be at risk.

Low RBSLs Mean More Sites (VI “Fail” Levels 10-1000 Times Lower)

- Typical Water & Soil Fail Levels:
 - Water: Benzene: 1 ug/L, PCE: 1 ug/L
- Soil Gas Levels “Failing” EPA VI Criteria
 - Subslab: Benzene: 0.0031 ug/L, PCE: 0.004 ug/L
 - At 5’: Benzene: 0.155 ug/L, PCE: 0.200 ug/L

For the vapor intrusion risk pathway, acceptable concentration levels are 10 to 100 times lower than acceptable levels for soil and water. So essentially, this increases the number of sites that have to be evaluated.

A Few Basics

- Units
- Attenuation Factors
- Risk Based Screening Levels (RBSLs)

To properly conduct a vapor intrusion assessment, a few basics need to be understood.

The Most Common Goof

1 ug/L Benzene equals:

- a) 1 ppbv
- b) 1 ppmv
- c) 330 ppbv
- d) None of the Above

Vapor units is one of the most common mistakes being made by practitioners in this field.

The correct answer is:

Attenuation (alpha) Factors

$$\alpha_{sg} = C_{indoor}/C_{sg}$$

$$\alpha_{gw} = C_{indoor}/(C_{gw} * H)$$

- Lower alpha means higher attenuation
- Current VI guidances:
 - EPA $\alpha_{sg} = 0.002$ for 5', 0.1 for sub-slab
 - NY Data Set implies 0.001 for sub-slab
 - Hydrocarbon α_{sg} likely <0.0001

A common term in the vapor intrusion “community” is the attenuation factor also called the alpha factor. The soil gas alpha factor is a ratio of the indoor air concentration to the soil gas concentration. The groundwater alpha factor is a ratio of the indoor air concentration to the groundwater concentration times its Henry’s constant.

Since indoor air values are lower than subsurface values, alpha factors tend to be less than 1, hence lower numbers mean greater attenuation. Thus, inverse alpha factors are often easier to understand.

The EPA draft guidance uses very stringent alpha factors, determined empirically from a limited data base or from the J-E model. More recent and larger data bases (IBM Endicott) are showing that the alphas should be orders of magnitude lower, especially for petroleum hydrocarbons.

Using Alpha Factors to Calculate Screening Levels

For Soil Gas:

$$C_{sg} = C_{indoor} / \alpha_{sg}$$

For Groundwater:

$$C_{gw} = C_{indoor} / (H * \alpha_{gw})$$

Example: C_{in} benzene = 0.31 ug/m³

$$C_{sg} (5') = 0.31 / 0.002 = 155 \text{ ug/m}^3$$

$$C_{gw} = 0.31 / (0.20 * 0.0005) = 3.1 \text{ ug/L}$$

By using alpha factors, one can calculate target levels for soil gas and groundwater by knowledge of the acceptable indoor air concentration. This is the method the EPA & many State guidances use to determine acceptable levels in the soil gas or groundwater.

What Risk Level?

- 1 in 1 million: Residences, Schools, Hosp
- 1 in 100,000: Commercial Settings (cumulative)
- 1 in 10,000: Acute (mitigate immediately & in some states evacuate premises)

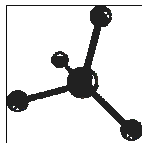
The allowable concentrations in indoor air, and hence in the vadose zone, depend upon the risk level and exposure time. Different agencies use different risk levels.

Why Are Indoor Air RBSLs So Low?

- Benzene: EPA: 0.31 ug/m³
- TCE: EPA: 0.022 or 1.0 ug/m³
- PCE: EPA: 0.41 ug/m³
- Values Assume Exposure Times of:
 - 24 hr, 350 days/yr, 30 years

Ultra Conservative Assumptions Lower Allowed Levels and Bring in More Sites

Allowable indoor air concentrations are so low because of the ultra conservative assumptions that are used, especially in regards to exposure time.



Low RBSLs Mean More Sites

(benzene $1\text{e-}6$ risk, default values)

Depth	Water (ug/L)	Soil (ug/kg)	
10'	2.2	5	
20'	3.3	10	
30'	4.5	15	
50'	6.8	50	

Federal EPA version

Some are Below or Near Lab DLs!



This table gives a summary of the value at which the VI pathway exceeds a 1 in 1 million risk for benzene using the DTSC version of the J-E spreadsheet. The default vapor intrusion criteria currently used by EPA, DTSC, OEHHA, and many other agencies are so conservative that few sites are screened out in the screening evaluation step. Some of the values are below laboratory detection levels meaning that even the non-detects fail. Further assessment requires more data which means more expense.

Screen-Out More Sites By:

- Adopting More Realistic Exposure Times
 - Workplace: 8 hrs/day, 250 days/yr, 25 yrs (5x)
 - School: 8 hrs/day, 180 days/yr, 6 yrs (30x)
 - Hospital: 24 hrs/day, 1 yr (30x)
- Adopt More Reasonable Distance Criteria
 - 100' Spatial for HCs Too Far Due to Bio
 - 100' Vertical for Cl Too Far
 - 5-10' Vertical for HC if O2 Present

More sites will be screened out if more realistic screening criteria are used such as more realistic exposure times, especially for schools and hospitals, and adopting more reasonable depth criteria. For State reimbursement funds, reasonable screening of sites will prevent draining the fund balances.

Allowable Soil Gas Levels (Benzene 1e-6 Risk)

State	Alpha	1/Alpha	Fail Level (ug/m ³)
NH	0.002	500	150
CA-DTSC	0.002	500	42
CT	0.0013	770	192
NJ (Subslab)	0.05	200	60
EPA Q4	0.1	10	3.1
EPA Q5	0.002	500	155
EPA Q6	0.1	10	3.1

A summary of the alpha factor and corresponding acceptable soil gas levels for various States and the EPA draft guidance shows large variation and illustrates the main point: the levels are variable from State to State.

Notice the difference in allowable values for the different EPA VI guidance questions.

Review of VI Guidances

- EPA OSWER
- State Guidances
- ITRC Guidance
- ASTM Guidance

In this part of the seminar, we will briefly review the EPA OSWER draft vapor intrusion guidance and some of the current policies among the States. If you are a consultant or RP, you need to know which agency has jurisdiction and what their vapor intrusion policy is in order to know what approaches are allowed and what the allowable levels are.

By allowable level, I mean the concentration of a contaminant in the indoor air, soil gas, groundwater, or soil that fails the upward vapor risk calculation. It can also be referred to as RBSL, PRG, acceptable value, look-up value, screening level, etc. This term will be used quite frequently throughout the remainder of this seminar.

OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)

Federal Register Notice - November 29, 2002

Fact Sheet: Evaluating the Vapor Intrusion into Indoor Air

Adobe PDF File [17 KB]

Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance) (Complete Document)

Adobe PDF File [3019 KB]

- Draft Guidance

Adobe PDF File [516 KB]

- Tables

Adobe PDF File [353 KB]

- Appendices A-C

Adobe PDF File [972 KB]

- Appendices D-F

Adobe PDF File [722 KB]

- Appendices G-I

Adobe PDF File [475 KB]

E-Docket is an on-line system that allows viewers to search the Agency's major public dockets on-line, view the index listing of the contents for the dockets included in the system, and access those materials that are available on-line. You may also submit comments on-line while this docket is open for public comment.

This is the web page for the EPA draft vapor intrusion guidance. From here, the guidance and other supporting materials can be downloaded. The document is a lengthy and difficult read. It is available at: (<http://www.clu-in.org/conf/tio/vapor/resource.cfm>)

Overview of Proposed Changes

EPA Draft VI Guidance

Nov. 2002

- Tier 1: **Primary** Screening
 - Q1: VOCs present?
 - Q2: Near buildings?
 - Q3: Immediate concern?
- Tier 2: **Secondary** Screening
 - Q4: Generic screening
 - Q5: Semi-site specific screening (alphas from charts & tables)
- Tier 3: Site-Specific Pathway Assessment
 - Q6: Indoor air (and/or subslab)

Fall 2005

- Tier 1: **Preliminary** Screening
- Q1: VOCs present?
 - Q2: Near buildings?
 - Q3: Immediate concern?
- Tier 2: **Generic** Screening
 - Q4: Generic residential and non-residential screening levels
- Tier 3: **External Site-Specific** Screening
 - Q5: More site-specific parameters (alpha from spreadsheet)
- **Tier 4: Internal** Site-Specific Assessment
 - Q6: Indoor air or subslab or both
 - Multiple lines of evidence

On the left is the current EPA OSWER guidance written in 2002. The EPA has proposed changes to the draft guidance that are supposed to go into effect in the summer of 2006 (right side of slide). The same 6 questions exist, but they have been divided into 4 tiers instead of 3 tiers (Q4, Q5, & Q6 all get their own tier). This was primarily done to allow more flexibility under Q5. Q5 now allows more sampling options external to the structure and more freedom in using the J-E model before having to go inside. This will allow the more versed consultants to be creative.

(Slide courtesy of Helen Dawson of EPA)

VI Guidance - Further Changes Being Contemplated by Writers Group (*DRAFT!*)

Fall 2005

- **Tier 1: Preliminary Screening**
 - Q1: VOCs present?
 - Q2: Near buildings?
 - Q3: Immediate concern?
- **Tier 2: Generic Screening**
 - Q4: Generic residential and non-residential screening levels
- Tier 3: **Exterior Site-Specific Screening**
 - Q5: More site-specific parameters (alpha from **J&E model Spreadsheet- Includes Future Use and commercial settings**)
- **Tier 4: Interior** Site-Specific Assessment
 - Q6: Indoor air or subslab or both
 - Multiple lines of evidence

Summer 2006 DRAFT!

- Tier 1: **Preliminary** Screening (site decision)
 - VOCs present?
 - Near buildings?
 - Immediate concern?
- Tier 2: **Source** Screening (site or subsite decision)
 - Generic residential (and non-residential) screening levels, applied to conservative (near-source) samples (existing or future buildings)
- Tier 3: **Pathway** Assessment (building decisions)
 - Worst-first assessment (inside out)
 - Multiple lines of evidence (pitchfork), including:
 - Near building soil gas and/or groundwater samples
 - Geological and/or biological attenuation
 - Constrained site-specific modeled attenuation, including future use and commercial settings
 - Interior (subslab, indoor air) sampling

The EPA is contemplating new changes based upon recent studies at Endicott NY and Stratford CT. The exterior site specific screening step will be much more conservative and require multiple lines of evidence. It will be much more difficult to get closure at this Tier. Tier 3 involves indoor assessment and will be much more intrusive and require more time. This is still being discussed by EPA and has yet to be finalized.

Slide courtesy of Henry Schuver, USEPA.

Summary of State VI Guidance

- Written:
 - NY, NH, MA, CT, PA, SC, LA, CO, WI, OR, ID, NJ, IN, MI, CA, MN, DL, ITRC, TN
- Working on a Draft:
 - FL, AZ, UT, WA, WI?
- Pondering:
 - ITRC survey implies at least 40 states

Many States have developed or are developing their own VI guidance because they don't agree with EPA's or they find it too confusing. Some States currently have written guidance, others have drafts, and others are pondering. Some States are still trying to figure it all out and have asked for training on the subject.

ITRC VI GUIDANCE

- Practical How-to Guide
- Stepwise Approach
- Investigatory Tools (Toolkit)
- Thorough Discussion of Mitigation
- Scenarios
- Classroom Training in 2007

ITRC has recently finished it's vapor intrusion guidance document. It consists of 2 documents: A practical guideline and a separate scenarios document. Internet training has already begun in 2007.

ASTM VI Task Group

- Focus on Property Transactions
- Screening Distances
- Legal Standards
- Third Meeting in 4/2007
- Due Out by End of 2007
- Update of Soil Gas Standard

ASTM has convened a technical workgroup to write a standard for vapor intrusion as it applies to property transactions. The standard is to be completed by the end 2007.

In addition, a separate task group has started working on updating the ASTM soil gas sampling standard.

Methods to Assess VI

- Indoor Air Sampling
- Predictive Modeling
- Measure Flux Directly
- Soil Gas Sampling
- Supplemental Tools/Data

In this part of the seminar, we will discuss the primary techniques used to assess the vapor intrusion pathway, including the pros & cons of each.

Indoor Air Measurement

- Pros:
 - Actual Indoor Concentration
- Cons:
 - Where From?
 - Inside sources (smoke, cleaners)
 - Outside sources (exhaust, cleaners)
 - People activities
 - Laborious Protocols, no control
 - Snapshot, limited data points
 - Expensive!!

Measuring indoor air might seem to be the most direct and simplest approach, but it has its share of problems. The biggest problem is background sources of contaminants. Many commonly used household products contain some of the target compounds of concern. For example, benzene from gasoline, PCE from dry cleaned clothes, TCA from degreasing cleaners. In addition, the protocols are laborious, intrusive, offer little control, and are expensive. For these reasons, the EPA and many States shy away from this method. However, this method may still be the method of choice if the contaminant of concern is not one commonly found in household products (e.g., 1,1 DCE).

Modeling

- Pros:
 - Can Use GW, Soil (?), Soil Gas Data
 - Relatively Easy
- Cons:
 - Not All States Allow
 - Which Version to Use?
 - Often Too Restrictive

The use of models to calculate an indoor air concentration, and in turn a health risk, is commonplace. Existing models use groundwater, soil, or soil gas data and are relatively easy to use. In general, if default parameters are used, they tend to overcalculate the risk for most situations.

Several versions currently exist with different default values for various parameters, so one must be careful to know what version they are using. Regulators must be careful with using modeling results for a number of reasons, one being that it is easy to try and change the values of some of the variables to get a passing value. As a result, some States will let you use the models as a screening tool, but not give complete closure.

Which One & Version to Use?


- Johnson-Ettinger Most Common
 - GW, soil, soil gas spreadsheets
 - Screen & advanced versions
 - 2003 and 2001 versions differ in some defaults
 - Hard to compare defaults vs actual values used
- New Version Being Written (2006)
 - One spreadsheet for all matrices
 - Summarizes defaults vs actual values used
- Others: Jury

The most common model currently being used in the Johnson & Ettinger (J-E) model. The EPA has written a number of spreadsheets that are based upon the model parameters and allow the use of groundwater, or soil, or soil gas data. The spreadsheets were updated in 2003 and are available from the EPA website referenced previously.

The EPA is currently rewriting the spreadsheets that will be very different in style from the existing ones. One spreadsheet will handle all matrices (groundwater & soil gas, but not soil phase data) rather than separate ones. The spreadsheet will show both default values and the user inputted values to facilitate recognition of what values were changed and by how much.

Other models do exist, but the J-E model is by far the primary one being used around the country.

Bookmarks Netsite: <http://www.epa.gov/athens/learn2model/index.html> What's Related

 **U.S. Environmental Protection Agency**

Modeling Subsurface Petroleum Hydrocarbon Transport

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Modeling Subsurface Transport of Petroleum Hydrocarbons

- **Modeling Subsurface Transport of Petroleum Hydrocarbons:** Fate, Transport and Modeling of Fuels and Fuel constituents
[Preview](#), [Current Status](#), [What's New](#)
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 - Fate and Transport
 - [Introduction](#) **New**
 - Fuel [Phases](#) in the Subsurface **New**
 - Modeling
- **OnSite** on-line calculators for site assessment calculations ([factsheet](#) (PDF, 2 pp., 259 KB, [About PDF](#)), [User's Guide](#) (PDF, 81 pp., 1.4 MB, [About PDF](#)))
[Calculator introduction](#), [full list of calculators](#)

This on-line calculator is a handy way to get a feel for screening levels without getting into the J-E spreadsheets. It uses EPA Federal default parameters for toxicity info, ventilation rates, etc. It can be found at to: http://www.epa.gov/athens/learn2model/part-two/onsite/JnE_lite.htm

How Well Does J-E Predict?

(From GW & Soil Data)

- Hydrocarbons
 - Calculated SG value too high by 10-1000x
 - No bioattenuation (10 to 1000x reduction)OVER PREDICTS IN ALMOST ALL CASES
- Chlorinated Solvents – Deep Source
 - Calculated SG value too high by 10-1000xOVER PREDICTS IN MOST CASES
- Chlorinated Solvents – Surface Source
 - Calculated SG value too low by 10-1000xUNDER PREDICTS IN MOST CASES

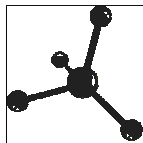
If you are going to use the models/spreadsheets, you need to be aware of the limitations. If the groundwater or soil spreadsheets are being used, the spreadsheet calculates the soil gas concentration assuming equilibrium partitioning. This is likely to give a soil gas concentration orders of magnitude higher than actual values. Also, for hydrocarbons, there is no allowance for bioattenuation. So, the result is that the spreadsheet is likely to over predict risk for hydrocarbons in almost all cases, unless right at the surface. For chlorinated compounds, the spreadsheet is also likely to over predict, but not as much since bioattenuation is not as prevalent. But, if surface sources exist, then vapor clouds might exist and the actual soil gas concentration might be higher than calculated, so in turn, the risk will be underestimated.

Because these models tend to over-predict the risk, especially from groundwater and soil data, you should be careful to verify the predicted risk if they show you are failing.

Direct Flux Measurement (Flux Chambers)

- Pros:
 - Direct Measurement of Intrusion
- Cons:
 - Proper Location?
 - Protocols Debated
 - How to Use Data?
 - Unsophisticated Audience
 - Regulatory Acceptance Limited

Surface flux chambers are attractive because they give a direct measurement of the flux into the structure or out of the soil. This eliminates the need to know the effective diffusivity and the uncertainty inherent in the models. The biggest drawback with chambers is whether they can be placed in the proper locations in an existing structure. Also, few regulators, consultants, or vendors have used them, so they are unfamiliar of the protocols to use and how to interpret the data. As a result, regulatory acceptance is limited. On undeveloped lots or houses with crawl spaces, surface flux chambers may be the best method to use. Flux chambers are also useful to verify if bioattenuation is eliminating contaminant fluxes from shallow vadose zone contamination.



Static Flux Chamber



Photo of a static flux chamber equipped with a LandTech GEM 2000 real-time oxygen, carbon dioxide, and methane analyzer used to collect data continuously.

Soil Gas Measurement

- Pros:
 - Representative of Subsurface Processes
 - Higher Fail Levels
 - Relatively Inexpensive
 - Can Give Real-time Results
- Cons:
 - Mass Transfer Coefficient Unknown
 - Overly Restrictive Default Criteria
 - Protocols still debated

Measurement of soil gas is by far the most preferred approach around the country. Actual soil gas data are reflective of subsurface properties, are less expensive than indoor air measurements, and allow real-time results. The fail levels are also higher so there is less chance to be chasing blanks.

There are some drawbacks, including the lack of knowledge of the effective diffusivity, very restrictive fail levels for sub-slab data, and debate over how & where to collect samples.

Soil Gas Sampling Methods & Issues

- Soil Gas Methods
- Sampling & Analysis Issues
- Where & When to Collect Samples
- Bioattenuation
- Other Tools/Approaches

This part of the training will focus specifically on soil gas sampling since it is currently the most preferred approach around the country and, if you have a vapor intrusion problem, the chances are high you will be required to oversee or work with soil gas data.

Which Soil Gas Method?

- Active?
- Passive? (limited use)
- Flux Chambers? (limited use)

Active method most often employed for VI

There are three types of soil gas methods. Active refers to actively withdrawing vapor out of the ground. It gives quantitative values. Passive refers to burying an adsorbent in the ground and letting the vapors passively contact and adsorb onto the collector. It does not give quantitative data and hence can not be used for risk applications, except for screening. Surface flux chambers were discussed previously.

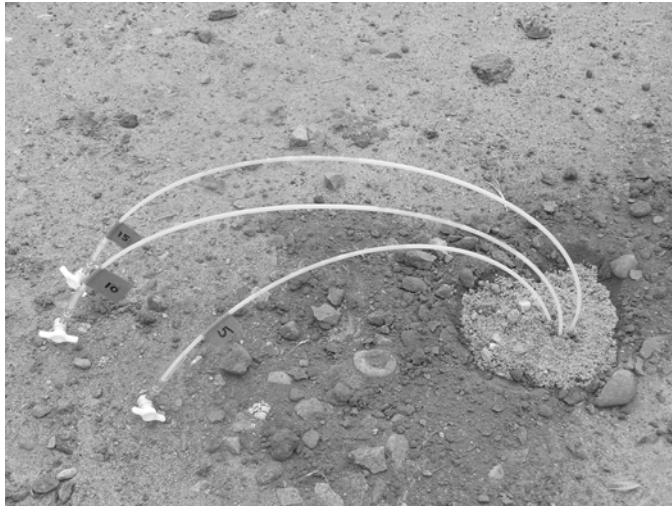
The active method is the one most applicable to risk assessments.

Sampling Through Rod



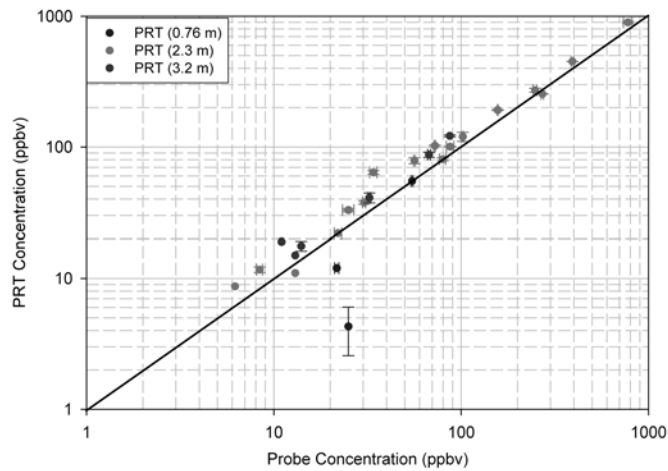
Collection through the probe rod is advantageous if only one sampling round is required. Seals at the base of the probe are advisable, especially if depths are shallow and larger volume samples (>1 liter) are collected.

Soil Vapor Implants



Soil vapor implants nested in same borehole at three different depths. This method is advantageous if repeated sampling is anticipated.

Comparison – DP to Tubes



Comparison data collected by Dom DiGiulio and others shows good agreement between the direct-push method and vapor well method.

Probe Considerations

- **Tubing Type**
 - Rigid wall tubing ok (nylon, teflon, SS)
 - Flexible tubing not (tygon, hardware store)
 - Small diameter best (1/8" or 1/4")
- **Probe Tip**
 - Beware metal tips (may have cutting oils)
- **Equilibration Time**
 - Effects by air knife, rotary, air percussion, sonic
- **Equipment Blanks**
 - Need to collect blank through collection system

Some of the issues that need to be considered when installing probes include:

Tubing Type: Small diameter tubing offers advantages over large PVC pipe. Flexible tubing tends to leak.

Probe tip: Metal tips may have blanks due to the cutting process.

Equilibration time: How long to wait, especially if air knives are used to clear holes or larger drill rigs are used.

Equipment blanks: need to collect blank through the collection system. Trip blanks not enough.

Soil Gas Sampling Issues

- Sample Size
 - Greater the volume, greater the uncertainty
 - Smaller volumes faster & easier to collect
 - Large purge vols require pumps & control
- Containers (Don't Chill!!)
 - Canisters: More blank potential. Higher cost.
 - Do NOT need to certify clean if $> 10 \text{ ug/m}^3$
 - Tedlars: Good for ~ 2 days. Easier to collect
- Flow Rate
 - Really not imp. But most agencies $< 200 \text{ ml/min}$

Lower detection levels requires more careful protocols. Important sampling considerations include sample volume, container type, flow rate, and leak testing to ensure valid samples are collected.

Smaller volumes require less complicated sampling systems and minimize the chances for leakage from the surface and desorption off soil.

Larger purge volumes require pumps and flow control which requires more effort and increases chance of errors. Three dead volumes should extract 88% or original air in the system volume, but what about sand pack and surrounding formation?

A variety of sample containers can be used depending upon volume required and storage time. All must be inert, tested clean, and handled properly (no cooling or heat).

Sample containers must be inert, clean, and handled properly (no cooling or heat). Canisters have longer holding times, but have the potential for blanks (carry-over from previous samples), cost more, and can be trickier to fill.

~~Tedlar bags are good for ~ 2 days, are less expensive, and suitable for~~
concentrations of 1 ppbv or higher.

Sample Volumes



A 6-liter Summa can is about the size of a basketball. A 400 cc mini-can is about the size of a baseball.

Lower volumes give more control on sample location, require less time to collect, and minimize chances of breakthrough from the surface or other sampling zones in nested wells.

For soil gas samples, most labs only require 100 cc of sample, so small canisters (<1 liter) are sufficient volume.

Soil Gas Sampling Issues

- Tracer/Leak Compound
 - Gaseous (He) or Liquid (IPA, Freons)
 - Imp for sub-slab & larger sample volumes
- Pumps
 - Collect on upstream side. Watch vacuum applied
- Rain
 - How long to wait after a rain event?
- Time-Integrated Samples?
 - Existing data does not show large variations

Tracer/leak compounds are required to ensure sample integrity. Both gaseous (He) and liquid tracers are used. The liquid tracers are operationally simpler and can cover more locations.

If pumps are used, samples should be collected upstream of pump and the applied vacuum should be minimized to avoid leaks.

Does rain influence soil gas concentrations? Probably not for depths greater than 3' and certainly not under paved surfaces.

Are time-integrated samples required ala indoor air samples? Most data do not show large temporal variations in soil gas concentrations.

Purging



For small diameter tubing ($1/8"$ or $1/4"$ OD), a simple and fast procedure to purge soil vapor probes is to use a disposable gas-tight syringe. Volumes can be carefully measured, the collector can get a feel for the permeability of the sampling zone from the syringe resistance, low vacuums and flow are applied, and no bulky hardware or power is required.

Sample Collection



Collection of a soil vapor sample in a mini-Summas (400 cc). Leak/tracer is typically applied prior to sample collection.

Sample Collection



Collection of a soil vapor sample in a larger Summa (6000 cc). Leak/tracer is typically applied prior to sample collection. Flow restrictor on top of canister. Note in this set-up, there is no gauge on the canister so the collector has no idea when the canister is filled.

Sample Collection



Collection of a soil vapor sample in a tedlar using a syringe. No power required, no complicated fittings. Leak/tracer can be applied prior to sample collection.

Flow rates can be easily controlled by this method and the presence of water also controlled. Once filled, the sample can be sucked into a canister if desired.

Beware of the Hardware



The tackle box on the left shows the required hardware to collect soil gas samples in canisters.

The syringe to the right is the only collection device required for on-site analysis of soil gas.

Additional Considerations

- Certified Clean Canisters
 - Not needed if $DL > 5$ to 10 ug/m^3
- Residual Vacuum in Canisters
 - Increases chances of leaks
- Dedicated Flow Restrictors
 - Not necessary if cleaned between samples

A few additional sampling considerations.

The “Key” Sampling Issues

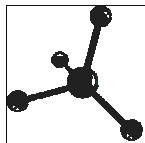
(That Directly Affect the Bottom Line)

- Get Enough Data Near/Around/Under
- Simpler Collection Systems
 - 20 to 30 samples/day (\$50-\$75 each)
 - Less chances for goofs & leaks
- Experience of the Collector/Consultant
 - Have they done this before?
 - Quality/experience of field staff? Sr or Jr?

Soil gas, like soil, is not homogenous in most cases. So you need enough data to give decent coverage near, around, or under the receptor. Simpler collection systems with small volumes are advantageous as there is less to go wrong and enable higher production per day (20+ samples per day). Less expensive analytical methods (8021, 8260) enable more analyses for reasonable cost. Real-time data can be extremely helpful to track soil gas contamination laterally and vertically.

The last important ingredient for cost effective and efficient VI investigations is the experience of the person/firm doing the collection. Is the collection being done by a firm that has prior experience? Is it a routine part of their services or an occasional part? Do they put experienced people in the field who can think or junior staff who aren't well versed? This applies to the consultant and their subcontractors.

All of these issues affect the investigation progress and hence the cost you end up paying (the ultimate bottom line).



Soil Gas Analysis Issues

(TO-14/15 or 8260 or 8021)

- All Methods Give Reliable Results
- Some States Require TO-15
- Detection Level Discriminator:
 - TO Methods: 1 to 10 $\mu\text{g}/\text{m}^3$
 - 8260 SIM: 10 $\mu\text{g}/\text{m}^3$
 - 8260: 50 $\mu\text{g}/\text{m}^3$
- On-Site Analysis:
 - Extremely Helpful for VI
 - Minimizes False Positives

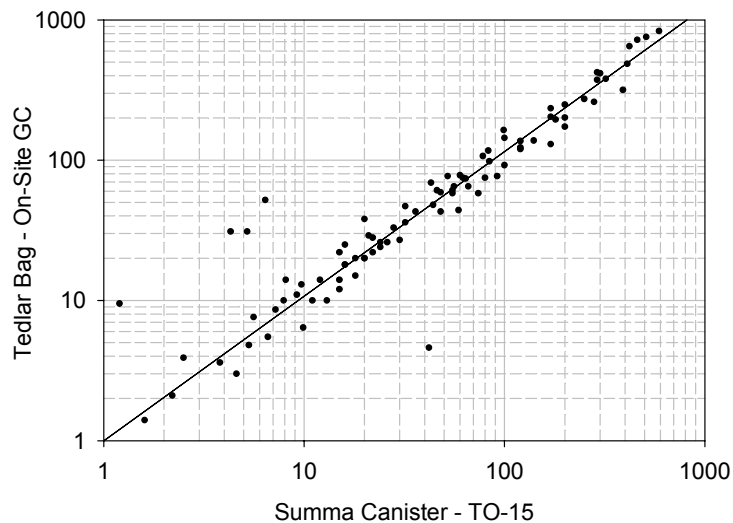


A variety of analytical methods are available to measure soil gas samples, but no federal guidance document exists specifying any one. Methods 8021 and 8260 are soil & water methods but give accurate results for soil gas samples at detection levels above 10 $\mu\text{g}/\text{m}^3$. The toxic organic methods (TO) are designed for ambient air samples, so they give accurate results for soil gas samples at much lower detection levels. The TO methods require extensive hardware and are far more expensive.

The criteria for selection should be which method(s) reach the required detection limits.

On-site data are extremely useful to ensure that the samples do not have tracer/leak levels above acceptable levels, provide real-time data for decision making, and to validate detections seen in the off-site data. If measured values are high, then the on-site methods (8021, 8260) are more appropriate to use than the ultra-sensitive TO methods. If on-site values are low or below detection, then the samples can be measured off-site by the TO methods.

On-Site 8021 Analysis vs. Off-site TO-15 Analysis



This slide shows a comparison of on-site analysis of TCE by 8021 out of a tedlar vs. off-site analysis by TO-15 out of a Summa canister collected by EPA-ORD at a test site. Correlation is excellent down to values as low as 2 ppbv.

Slide courtesy of Dr. Dominic DiGuilio, EPA-ORD

	Project: Project Number: Project Manager:	Reported: 23-Feb-07
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Volatile Organic Compounds by EPA TO-15

H&P Mobile Geochemistry

Analyte	Result	Reporting Limit	Units	Dilution Factor	Batch	Prepared	Analyzed	Method	Notes
(E702061-02) Vapor Sampled: 15-Feb-07 Received: 16-Feb-07									
Bromodichloromethane	ND	550	ug/m ³ Air	100	EB72105	20-Feb-07	20-Feb-07	EPA TO-15	
cis-1,3-Dichloropropene	ND	500	"	"	"	"	"	"	
4-Methyl-2-pentanone	ND	500	"	"	"	"	"	"	
trans-1,3-Dichloropropene	ND	500	"	"	"	"	"	"	
Toluene	ND	500	"	"	"	"	"	"	
1,1,2-Trichloroethane	ND	500	"	"	"	"	"	"	
2-Hexanone	ND	500	"	"	"	"	"	"	
Dibromochloromethane	ND	500	"	"	"	"	"	"	
Tetrachloroethene	140000	500	"	"	"	"	"	"	
1,2-Dibromoethane (EDB)	ND	500	"	"	"	"	"	"	
Chlorobenzene	ND	500	"	"	"	"	"	"	
Ethylbenzene	ND	500	"	"	"	"	"	"	
m,p-Xylene	ND	500	"	"	"	"	"	"	
Styrene	ND	500	"	"	"	"	"	"	
o-Xylene	ND	500	"	"	"	"	"	"	
Bromoform	ND	2000	"	"	"	"	"	"	
1,1,2,2-Tetrachloroethane	ND	500	"	"	"	"	"	"	
4-Ethyltoluene	ND	500	"	"	"	"	"	"	
1,3,5-Trimethylbenzene	ND	500	"	"	"	"	"	"	
1,2,4-Trimethylbenzene	ND	500	"	"	"	"	"	"	
1,3-Dichlorobenzene	ND	1000	"	"	"	"	"	"	
Benzyl chloride	ND	500	"	"	"	"	"	"	
1,4-Dichlorobenzene	ND	1000	"	"	"	"	"	"	
1,2-Dichlorobenzene	ND	1000	"	"	"	"	"	"	
1,2,4-Trichlorobenzene	ND	1000	"	"	"	"	"	"	
Hexachlorobutadiene	ND	1000	"	"	"	"	"	"	
<i>Surrogate: 1,2-Dichloroethane-d4</i>									
		96.5 %	80-120	"	"	"	"	"	
<i>Surrogate: Toluene-d8</i>									
		105 %	80-120	"	"	"	"	"	
<i>Surrogate: 4-Bromofluorobenzene</i>									
		89.6 %	80-120	"	"	"	"	"	

Here is an example of what happens to reporting limits with high concentration soil gas samples. The value for PCE is 140 ug/L (140,000 ug/m³). The TO-15 method upper limit was 100 times lower, so the sample had to be diluted 100 times. Consequently, the reporting limit for all compounds increased to levels higher than could have been reported by Method 8260. This situation is common at UST sites, dry cleaners, and commercial facilities using solvents.

High SG Concentrations Create Headaches

- Typical Soil Gas Concentrations:
 - Benzene near gasoline soil: >100,000 ug/m³
 - TPH vapor: >1,000,000 ug/m³
 - PCE under dry cleaner: >100,000 ug/m³
- TO-15 Maximum Conc: 2,000 ug/m³
 - Must do large dilutions, DL goes up
 - False positives from hot samples
- Canister & Hardware & Instrument Blanks

Typical soil gas concentrations at leaky UST, dry cleaner, and industrial solvent sites are in the 100,000s to 1,000,000 of ug/m³. But, for 1 in 1 million risk, the risk-based screening levels are less than 10 to 100 ug/m³. This large concentration range creates a number of analytical headaches.

The TO-methods and hardware (canisters, flow chokes) are not designed for such high concentrations. System carryover, large dilutions, and contaminated canisters increase the potential for false positives, raises reporting levels, and gives air labs logistical fits which limits the utility of these methods.

The 8260 and 8021 methods can't get lower than 10 to 100 ug/m³ so they may not reach required DLs.

In practice, a combination of these methods is the best approach. If expected values are high, then the 8021 & 8260 are advantageous to use than the ultra-sensitive TO methods. If expected values are low, then the TO methods offer advantages.

Not All TO-15s Are Alike

- Standard Method QA/QC Poor & Does Not Meet Many States Requirements (CA-EPA, NJ, NY)
 - Can use standard for a year!!
 - No second source standard
 - No surrogates
 - Wider calibration acceptance windows
- Beware the “Wal-Mart TO-15”
 - Only use labs that have upgraded method
 - Only use lab that has a certification

The TO-15 analytical method has been advertised as the “Gold Standard”, but actually, the QA/QC is very poor and does not match the requirements of many State agencies. Further, it may have difficulty meeting the legal challenge. Incredibly, most State regulatory personnel don’t realize this. Some States, like NJ, have published a more exacting method than the standard method.

The higher-quality labs have upgraded the method to meet more exacting requirements required by the EPA SW-846 methods or any specific State regulatory requirements, such as second source standards & surrogates.

Beware the “Wal-Mart TO-15”. To ensure that you are getting a quality analysis, only use labs that can show they have upgraded the method QA/QC and have a certification from some NELAC or a State agency.

How Often to Sample?

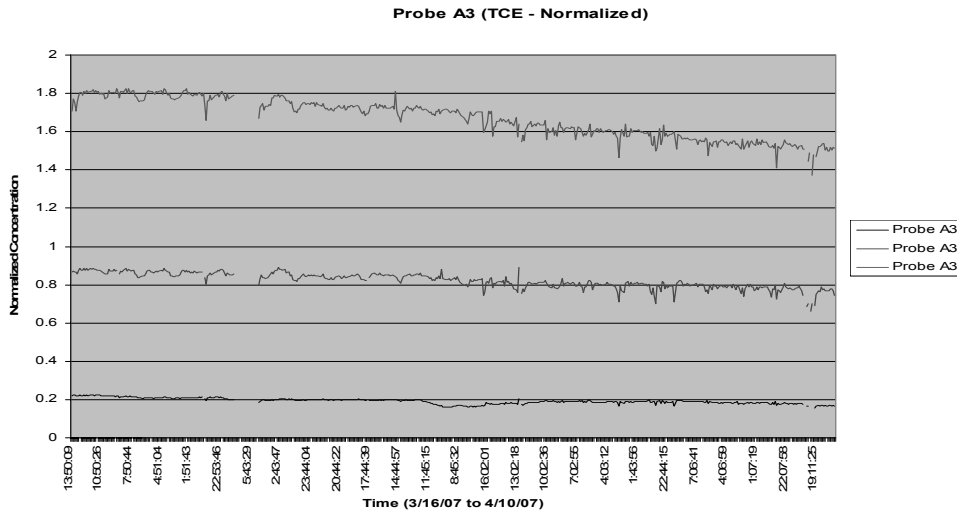
- Closer to Surface, More Variability
 - 3' to 5' bgs generally considered stable
 - Upper few feet likely variable
 - Recent data show repeatability <5' bgs
- Seasonal Effects
 - Most studies show less than 5x
 - Heating/cooling of structure more imp
 - Heavy periods of rain
 - Fluctuation groundwater

The closer to the surface, the more the potential temporal variation. Depths of 3' to 5' below the surface are generally considered stable and repeatable. Recent studies imply soil gas concentrations are stable at depths shallower than 5' bgs.

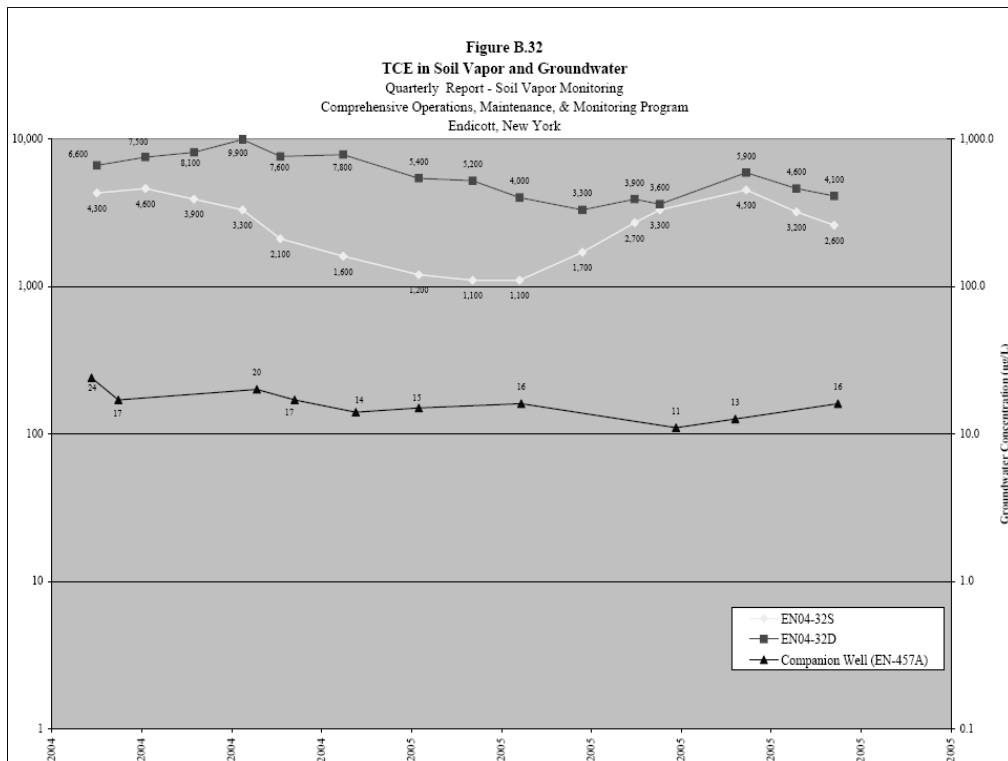
Temporal variations have been shown to be less than a factor of 5 even in colder environments. Larger variations may be seen due to effects caused when heating or ventilation systems are operative, during heavy periods of precipitation, and if the groundwater levels fluctuate.

If conditions suggest that temporal variations may be significant and if the measured values are close to the fail level, then repeated sampling may be appropriate and vapor implants are a good approach.

Soil Gas Temporal Study



This is a plot of data recently collected for an EPA funded study by an automated instrument at Vandenberg AFB site from three probes at the same location but at different depth (3', 8, & 17' bgs). This plot consists of over 500 points per probe collected once per hour over a 4 week period from mid March to mid April 2007. The soil gas concentrations varied by less than 10% over these four days even for probes only 3 feet below the surface.



Recent data collected over 15 months from Endicott NY show very low variations in deep soil gas (max variation less than factor of 2) and sub-slab soil gas concentrations (max variation less than factor of 4). Hence, in most cases, it is not necessary to collect samples more than once.

Slide courtesy of Dr. William Wertz, NY-DEC

Where to Sample Spatially

- Source Not Immediately Below
 - Collect on side towards source
 - Collect on other sides of structure
 - Preferential pathways at edges & conduits
- Source Below
 - Collect around structure before sub-slab
 - Get decent coverage
- Representativeness
 - Need enough points.

There is currently much debate on where to collect samples and no existing protocols or guidance. So, common sense comes into play. If source not directly below, collect samples between the structure and the source at a depth that is deep enough to give repeatable results. Collect in any known preferential pathways, such as utility lines.

If the source is below, for legal issues, it is often times preferred to collect around the structure before going inside the structure.

Spatial averaging allows a better representation of what's below the structure. One approach is to collect samples on all sides of the house and use an averaging method to get a value under the structure footprint.

If real-time data exist, add additional points depending upon the results. If not, collect extra samples spatially and analyze if necessary.

Where to Sample Vertically

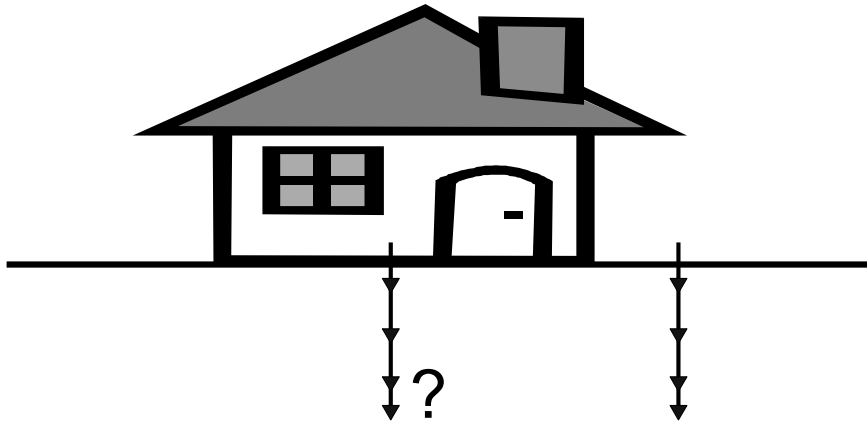
- Initially Deep Enough for “Stable Data”
 - For HCs, 5’ below structure
 - For Cl-HCs, at GW or mid-way to GW
- Shallower Samples (<5’ bgs)
 - Zone of bioattenuation
 - Zone of surface reaeration
- Vertical Profiles
 - Determine direction of source
 - Can aid in documenting bioattenuation

The closer you get to the surface, the greater the chance that surface processes such as atmospheric pumping, precipitation, & advective flow from structures will affect the soil gas. So, initially, sample 5’ bgs to get below this zone if the source is below.

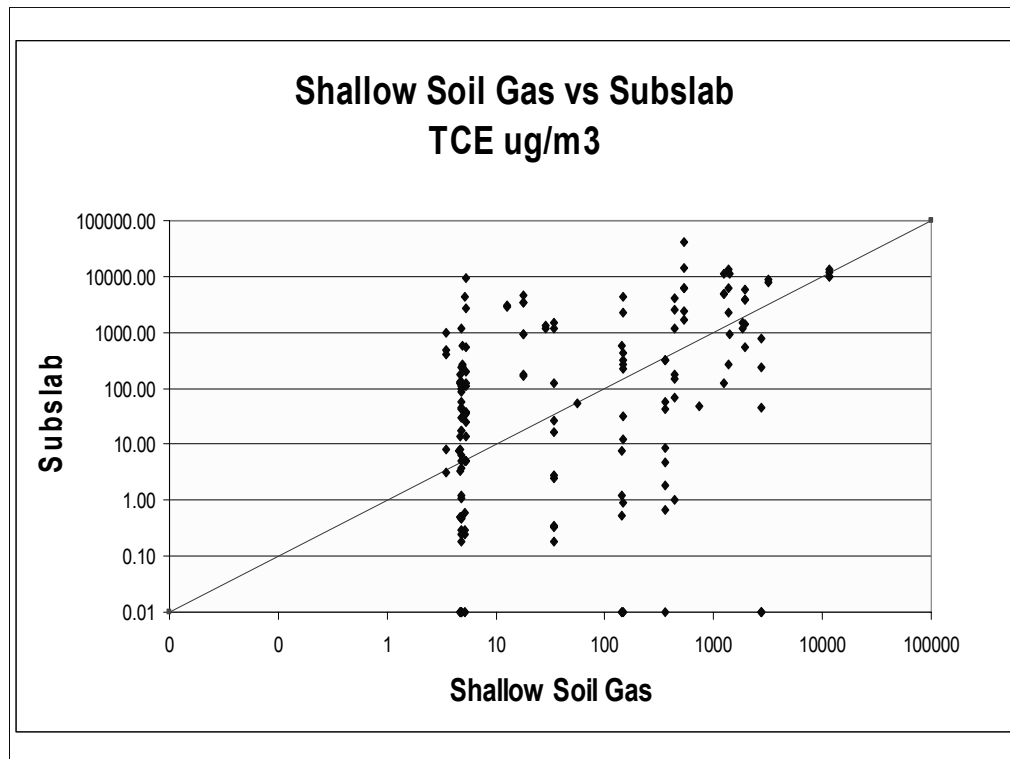
In some cases, collect samples shallower than 5 feet to document that the concentrations are attenuating due to bioattenuation in the uppermost vadose zone.

Vertical profiles also will aid in determining the direction of the source.

Sub-Slab vs. Near-Slab Profiles



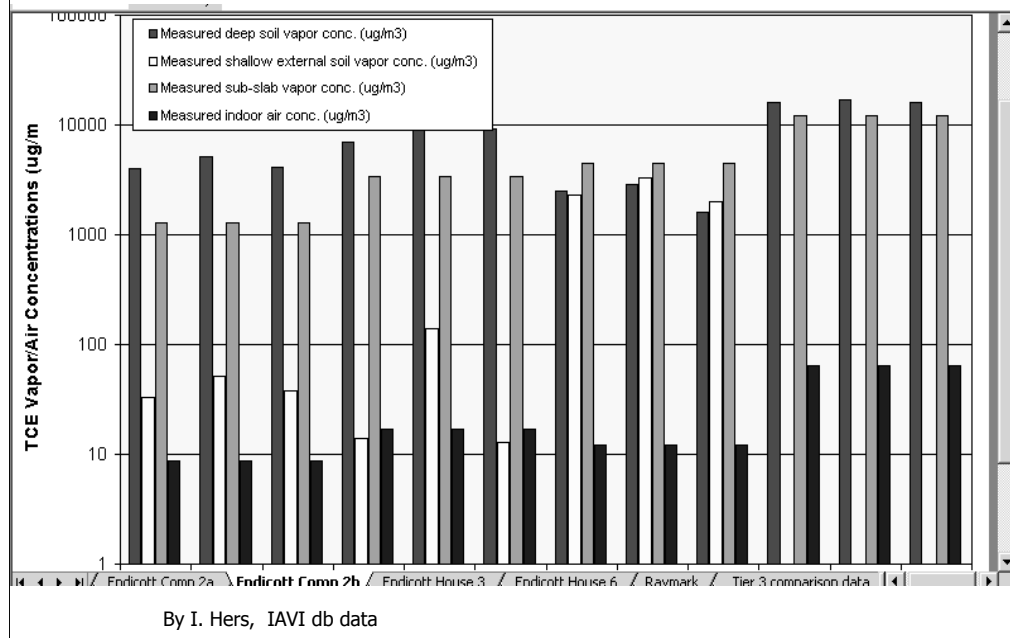
Are sub-slab samples the best to collect?



Data from Endicott NY show a poor correlation between sub-slab soil gas and exterior, shallow soil gas. However, the data were not always collected at the same time and many of the exterior samples were collected far away from the slab.

Slide courtesy of Dr. William Wertz, NYDEC

Sub-slab vs Deep Soil Gas



Another view of the Endicott NY data showing that deeper soil gas concentrations (>10' below the foundation) nearly always are higher than the sub-slab soil gas concentrations and hence are more conservative to use.

Slide courtesy of Henry Schuver, EPA.

Sub-Slab vs. Near-Slab

- EPA & Some States Prefer Sub-slab
 - “Ponding” effect under slab?
 - Remember: Balls don’t run uphill
- Good Comparison Database Lacking
- Very Intrusive. Attorney Time.
- If O₂ High Around Slab, Near-slab OK
- For Cl-HCs, at GW or mid-way to GW

The draft EPA VI guidance strongly advocates sub-slab samples and some State agencies agree. Some are fearful that the contaminants build-up under the slab (“ponding effect”). But, sub-slab sampling is intrusive and often leads to legal complications.

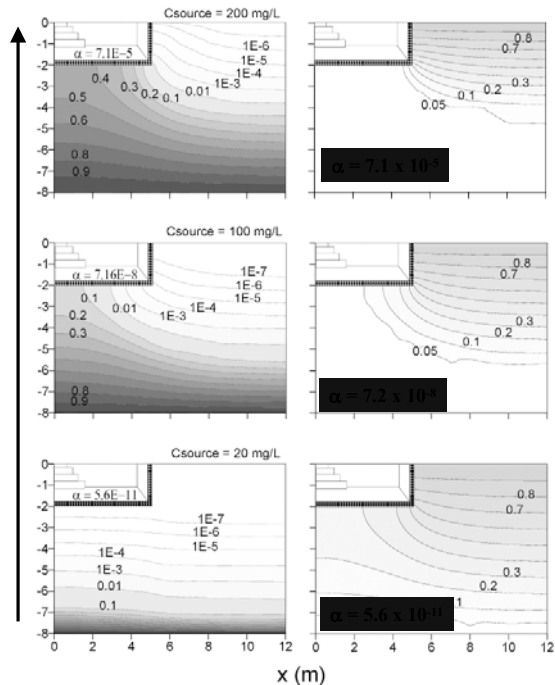
For hydrocarbons, if high oxygen levels (5%) exist all around the slab at a shallow depth, and the slab small (like at a residence), there is a good chance that bioattenuation & reaeration under the slab are occurring and sweeping contaminants clear.

For chlorinated hydrocarbons, by Fick’s law, the sub-slab concentration can be no higher than the source concentration. So if the the source is below the receptor, collection of samples at the source depth should reflect the maximum sub-slab concentration for sites where inside access is a problem.

Effect of Source Concentration

$[\lambda = 0.18 \text{ h}^{-1}]$

Results suggest that there may be source vapor concentrations that are of little concern if soil gas beneath the foundation is well-oxygenated (e.g., groundwater plume sources)



Recent modeling by Dr. Lilian Abreau (Geosyntec Consultants) and Dr. Paul Johnson (Arizona State University) has shown that for hydrocarbons sources in the soil vapor less than 20 mg/L, there is unlikely to be any vapor intrusion risk. The benzene vapor concentration in equilibrium with gasoline is only 7.8 mg/L and data from 100 sites show maximum benzene vapor concentrations of less than 1 mg/l! So, unless the source very close to the receptor, there is no need to worry.

Slide courtesy of Dr. Lilian Abreau & Dr. Paul Johnson

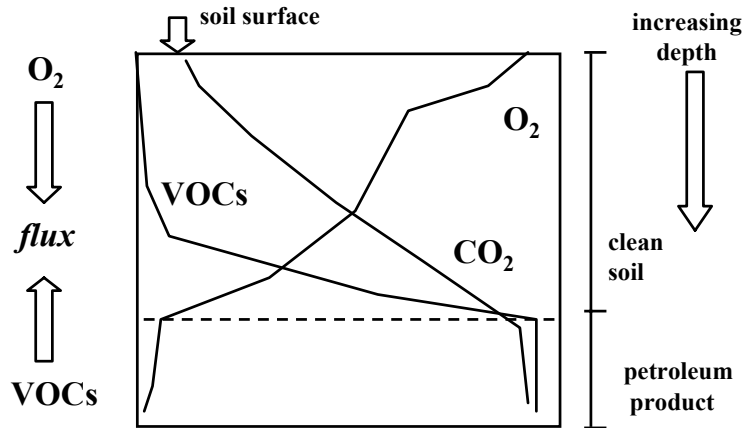
Bioattenuation of HCs

- Existing data suggest O₂ effective barrier
- Attenuation > 10,000 times
- Vertical profiles of COC & O₂
- DNA can confirm presence of tropic bugs

A vast number of studies have been performed clearly demonstrating that the bioattenuation of hydrocarbon vapors occurs in aerobic soils. In general, the studies show that when oxygen levels are 5% or greater and a couple feet of vadose zone exist between the source and receptor, that the hydrocarbons aren't escaping into the receptor. Attenuation factors can be as high as 10,000 times ($\alpha = 0.0001$).

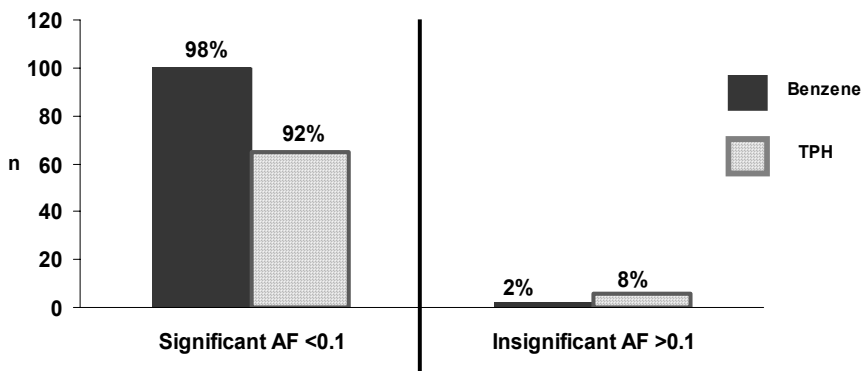
Documentation that this process is occurring is done by collecting vertical profiles of the soil gas for the hydrocarbons, oxygen, and carbon dioxide. If shown to occur, many agencies are conservatively allowing a factor of 10 to 100 reduction in the alpha factor.

Theoretical Bio Profile



This is the theoretical profile for hydrocarbon VOCs, CO_2 , and oxygen in the soil gas with depth where bioattenuation is active.

**Sample Events and % Attenuation of
Benzene and TPH**
Study Data Set Events: 102 Benzene, 71 TPH
n = # vapor sample events



SIGNATURE CHARACTERISTICS OF BIO-ATTENUATION

- 5 feet clean coarse-grained or 2 feet of fine-grained soil overlies contaminant source
- Vapor concentrations decrease significantly vertically away from source
- O₂ depleted and CO₂ enriched near the source, O₂ enriched and CO₂ depleted with increasing distance from the source
- O₂ minimum range 3% to 5%

An analysis of hydrocarbon sites from around the country has been performed by Robin Davis of the Utah DEP. Her analysis shows that 92% of TPH contaminated sites and 98% of benzene contamination have significant (>100 times) reduction in concentration due to bioattenuation.

Slide courtesy of Robin Davis of Utah DEP

Supplemental Tools/Data

- Site Specific Alpha Using Radon
 - Factor of 10 to 100. \$100/sample
- Indoor Air Ventilation Rate
 - Factor of 2 to 10. <\$1,000 per determination.
- Real-Time, Continuous Analyzers
 - Can sort out noise/scatter
- Pressure Measurements
 - Can help interpret indoor air results

If the soil gas levels exceed the fail levels, there are some other inexpensive tools/data that can be applied to better evaluate some of the default model parameters. These tools/data have much more influence on the resulting risk than measurement of soil porosity and cost about the same.

Radon can be used to determine a site-specific alpha that may be 10 to 100 times lower than the default alpha allowed.

Tracers can be used to measure the room ventilation rates and may give values 2 to 10 times higher than the default value, especially for commercial sites.

For HCs, vertical profiles of the soil gas can demonstrate bioattenuation. In some States, the agencies allow for a 10 times reduction in risk if bioattenuation is demonstrated. Although the DTSC guidance recognizes bioattenuation, it currently gives no indication as to how the data will be interpreted.

Real-time analyzers can be used to locate problem houses, preferential pathways into structures, or sort out background scatter. Pressure measurements are helpful with indoor air data to possibly show a background source.

Pressure measurements are helpful with indoor air data to possibly show a

Building Ventilation Rates

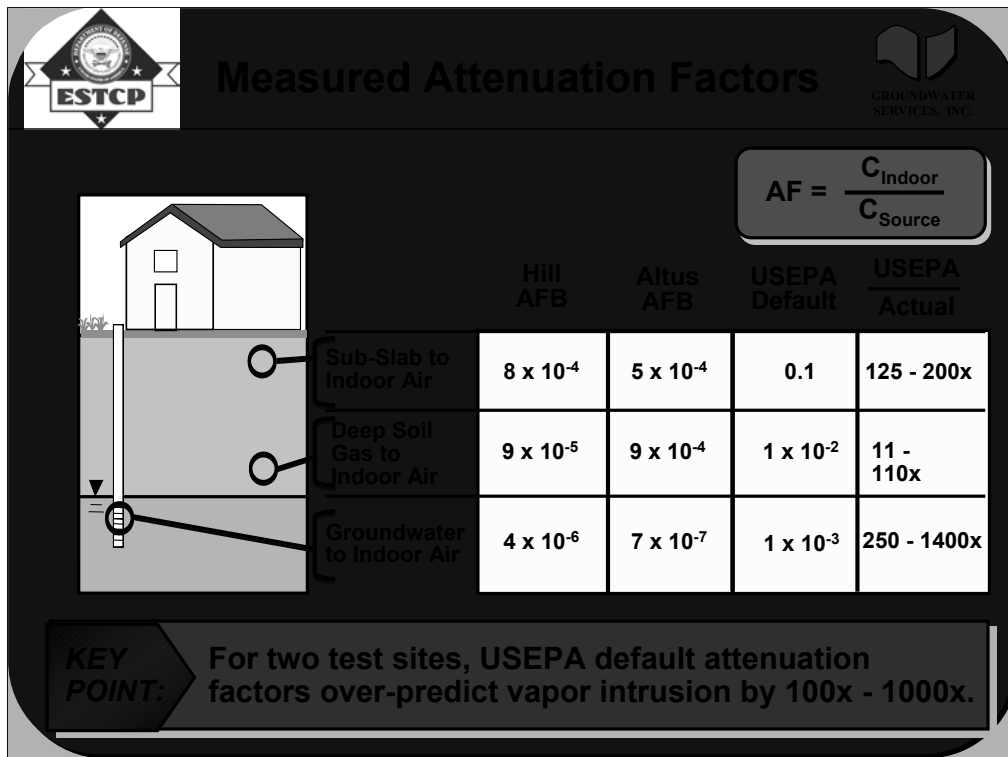
ANSI / ASHRAE Standard 62.1 – 2004
Ventilation for Acceptable Indoor Air Quality

<i>Building Type</i>	<i>Air Exchange Rate (# / day)</i>
USEPA Default (Residential)	6
Office Space	12
Supermarket	17
Classroom	68
Restaurant	102



Building ventilation rates for non-residential structures are known to be much higher than the default value allowed by the EPA in their J-E spreadsheet. Using the proper ventilation rate can lower the risk by as much as a factor of 20.

Slide courtesy of Dr. Thomas McHugh, GSI, Houston, TX



Slab attenuation factors measured by GSI at 2 sites using radon are 2 orders of magnitude below current default values.

Slide courtesy of Dr. Thomas McHugh, GSI, Houston, TX

Practical & Cost Saving Dos

- Use Reasonable RBSLs
- Have Reasonable Distance Criteria
- Use Simpler, Faster Sampling Systems
- Use Less Expensive Methods (8021, 8260)
- HCs: Vertical Profiles Around Structure
- Use Radon for Slab-Specific Alpha
- Measure Ventilation Rate
- Have Competent Consultants & Subs

These are things you want to do/allow to practically and cost effectively assess this risk pathway.

Practical & Cost Saving Don'ts (Things Not to Do or Require)

- Don't Require a Detailed Site Conceptual Model
- Don't Require TO-Analytical Methods
- Don't Require SS Canisters (& Certified Clean)
- Don't Worry About Irrelevant SG Procedures
- Don't Require Repeated Analysis if Values $<10x$
- Don't Require All Soil Physical Properties
- Don't Require Sub-Slab or Indoor Air
- Don't Require Meteorological Data

Some things you don't want to do or require if you want to keep the assessment from getting too complicated or costly.

Previews of the VI Future

- VI Likely to be a Concern at Your Sites
- Variable Regulatory Guidance Makes Assessment Tricky & Slow
- ASTM Standard Coming
- Hydrocarbons to be Less of a Concern

Here are some predictions & previews of the vapor intrusion pathway for the next few years.

VI Sampling Documents

- Overview of SV Methods (www.handpmsg.com)
 - LustLine Part 1 - Active Soil Gas Method, 2002
 - LustLine Part 2 - Flux Chamber Method, 2003
 - LustLine Part 3 - FAQs October, 2004
 - LustLine Part 4 – More Q&A, Summer 2006
- Regulatory Guidance
 - ITRC toolkit (www.itcreweb.org)
 - CA-EPA Soil Gas Advisory (www.dtsc.ca.gov)
 - NY, NJ, MO Soil Gas Documents

A summary of existing documents on soil gas methods can be found at these locations:

VI Documents

- Soil Gas Sampling SOPs (www.handpmg.com)
 - Soil Gas Sampling, Sub-slab Sampling, Vapor Monitoring Implants, Flux Chambers
 - EPA-ORD Sub-slab SOP–Draft, Dr. Dom DiGuilio (www.iavi.rti.org/resources)
- Other
 - API Soil Gas Document (www.api.org/bulletins)
 - Robin Davis Lustline Article on Bioattenuation (Lustline March 2006, www.neiwpcc.org)

More documents.

VI Websites & Links

- www.handpmg.com
 - Soil Gas Information
 - Other Site Assessment Methods
- www.itrcweb.org
- www.api.org
- [http:iavi.rti.org](http://iavi.rti.org)

Useful vapor intrusion websites.

Case Histories

- Active Station in Residential Area
- Former Station in Commercial Area

VI Case History #1

Summary of Steps

- Step 1: Have Site Conceptual Model
- Step 2: What Agency Has Oversight?
- Step 3: Calculate Risk from Existing Data
- Step 4: Choose Assessment Method
- Step 5: Determine Screening (Fail) Levels
- Step 6: Design Sampling Program
- Step 7: Collect & Interpret Data
- Step 8: Use Other Tools

Here are the steps to follow for assessing the vapor intrusion pathway at a site. We will apply these to a case history of an active gasoline station in an urban location with residential receptors and an on-site convenience store.

VI Case History

Step 1: Brief Site Conceptual Model

- Active station – LA
- Contaminated soil southern portion
 - Benzene 100 mg/kg, TPH 10,000 mg/kg @ 20'
- NAPL on GW @ 25' bgs
- Lithology: sandy soil
- Residence located ~20' to west
 - Dirt Crawlspace
- Does Acute Risk Exist?

A real case history to demonstrate the vapor intrusion assessment process for a typical gasoline station site:

Step 1: Brief site conceptual model. Key information required:

- What types of contaminants at what concentrations in what media?
- Is contamination well defined?
- What types of receptors (houses, retail, commercial industrial) and what structure type (slab, basement, crawlspace)?
- What is location of contaminant relative to structure?
- Is the Risk Acute?

VI Case History

Step 2: What Agency Has Oversight?

- LA-RWQCB
 - Generally Follow DTSC Guidance
 - Use Outside Risk Assessor
- Who Are Case Worker and Assigned Risk Assessor?

Step 2: What Agency are you dealing with and what case worker? Does the agency use an outside risk assessor and if so, who is it?

VI Case History

Step 3: Calculate Risk from Existing Data

- From Existing Lookup Tables
- From Default Alpha if Allowed
- From J-E Spreadsheet
- Cumulative Risk?

Step 3: Use any existing groundwater or soil gas data to compare to risk based screening levels. Use either the agency's screening levels, default alpha method, or the J-E spreadsheet if allowed.

Is there more than 1 compound of concern? If so, cumulative risk must be considered.

VI Case History

Step 3: Calculate Risk from Existing Data

- Benzene & Naphthalene the Drivers
- From Groundwater:
 - Use EPA J-E GW Spreadsheet
 - GW “Fail Level” = ~2 ug/L for slab
 - Benzene Solubility: 44,000 ug/L
 - Fail By: ~20,000 times
- From Soil Data
 - “SG Fail Level” = $0.000084 / .001 = 0.084$ ug/L
 - Calculated SG Value from Soil: 40,000 ug/L
 - Fail By: 400,000 times

Step 3: Use any existing groundwater or soil data to compare to risk based screening levels. For groundwater data, use either the agency’s screening levels, default alpha method, or the J-E spreadsheet for groundwater if allowed (the spreadsheet was used in the example).

For soil data, calculate the equilibrium soil gas concentration from the soil concentration (easiest way to do this is use the EPA spreadsheet called SL-screen) and then compare the calculated soil gas concentration to the allowed soil gas concentration determined from either the agency’s screening levels, default alpha factors, or the J-E spreadsheet for soil gas if allowed.

For this example, both approaches show the calculated risk fails by 4 to 5 orders of magnitude! This is consistent with the fact that the spreadsheets and alpha factors are ultra conservative.

VI Case History

Step 4: Choose Assessment Method

- Benzene >RBSL in Outdoor Air
- Soil Phase Data Not Allowed
- GW Data Over-predicts Risk
- Bioattenuation Will be Active

Soil Gas Data Best Method

Step 4: Determine what type of data are best to collect to assess the pathway. Ambient benzene values in central SD (location of this site) exceeds allowable risk levels by a factor of 10 to 100, so collection of indoor air data not wise. Houses also tend to have many benzene sources, further adding to the background.

Groundwater and soil data tend to overpredict the risk, so soil gas data the best type to collect.

The sampling program will be designed to demonstrate bioattenuation is active and to stay out of the homes to reduce the liability risk.

VI Case History

Step 5: Determine SG Screening Levels

- From Default Alpha:
 - $C_{sg}(5') = 0.31/0.002 = 155 \text{ ug/m}^3$
- If Naphthalene Required:
 - Cumulative Risk Drops Level
 - Risk Level = $155/2 = 78 \text{ ug/m}^3$

Step 5: Determine the soil gas screening levels so that the proper analytical method is employed and real-time decisions can be made. For this example, we use EPA's target benzene levels, alpha factors, and spreadsheets.

If cumulative risk is considered, the screening level drops by a factor of 2.

Use 78 ug/m³ as target level for 5 foot soil gas samples.

VI Case History

Step 6: Design Soil Gas Program

- Client: Stay Off Residence Property
- Collect at Property Line @ 5'
- Measure VOCs on-site by 8260 & O2

Step 6: Design the soil gas analytical & sampling program.

Detection levels of 78 ug/m³ can not be obtained by on-site 8260, but high concentrations are expected based upon the groundwater and soil data. So, use on-site 8260 (DL of approximately 100 ug/m³) with off-site TO-15 combination approach. Bring Summas to collect samples that are not by 8260. Also be prepared to measure oxygen to demonstrate the bioattenuation barrier.

Collect samples at 5 feet bgs at the property line towards the residence. If results are below 8260 DL, collect samples for off-site TO-15 for analysis down to 40 ug/m³. If samples have measurable values by 8260, be prepared to collect samples at shallower depths to demonstrate bioattenuation. Measure for oxygen also.

To support the bioattenuation argument, collect vertical profiles of soil gas samples over the worst locations to demonstrate attenuation towards the surface. If bioattenuation also shown to be happening at the worst locations, the agency will be more likely to accept it and possibly allow higher risk-based screening values.

VI Case History

Step 7: Collect & Interpret Data

- 5' Soil Gas Data along Property Line:
 - Benzene: 200 to 1000 ug/m³
- 3' Soil Gas Data along Property Line:
 - Benzene: 50 to 100 ug/m³
- Indicates Bioattenuation Active

Step 7. Collect & Interpret Data.

Preliminary soil gas data collected along property line showed benzene values of 200 to 1000 ug/m³ at 5 feet bgs. These values are nearly 100,000 times below equilibrium values indicating bioattenuation is active. But, these data exceed the regulatory screening level by a factor of 10 to 20.

Data at 3' bgs are very close to allowable levels.

The values at the residences are likely to be even lower since it is further from the contamination source.

Need to collect data to support this argument.

VI Case History

Step 7: Vertical Profiles

- 3 Locations at Property Line All Show Bio
- Same Will Be True Near Residence
- Values Should Be Lower Near Residence
- Take 1' or 2' Samples?
- Confirm With Flux Chambers?

Make Case that Pathway Incomplete

Step 7. Collect & Interpret Data.

Vertical profiles show consistent pattern at all 3 locations with nearly complete hydrocarbon attenuation towards surface. Same process will be occurring near the house.

Collect a soil gas sample at one or two shallower depths (1', 2') to prove that values fall off below allowable levels near the surface. On-site analysis likely not sensitive enough so be prepared to collect samples for off-site TO-15 analysis if the on-site analysis is below detection.

If agency won't accept data soil gas data less than 3' bgs, consider use of flux chambers.

VI Case History

Step 8: What Next? (Use Other Tools)

- Primary Residence
 - Soil gas near and around structure
 - Flux chamber in crawlspace?
- What About Other Residences?
 - Any within 100' of plume or soil in any direction?
- What About Risk to Current Station?
 - Exposure time ~5 times less
 - Sub-slab samples likely better. Radon
 - Measure ventilation rate since much higher

Step 8: What other tools or data to collect next if the shallow soil gas above acceptable levels or regulators don't close the case?

For the primary residence, collect soil gas data closer to and possibly all around the residence. Use on-site 8260 data to ensure no "surprises" (hot samples are detected), but be prepared to collect all samples for off-site TO-15 to meet required fail levels. Measure for oxygen also on-site. If oxygen above 6% in the soil gas samples around the house and on-site values below 8260 DL, then values directly under the house unlikely to be higher than near the house.

If the data near the house suggests a potential problem, flux chamber measurements in the dirt crawlspace would be a good approach.

Are there any other residences within the regulatory limits in a different direction? Then collect shallow soil gas data near the property border and follow the same logic path for this house.

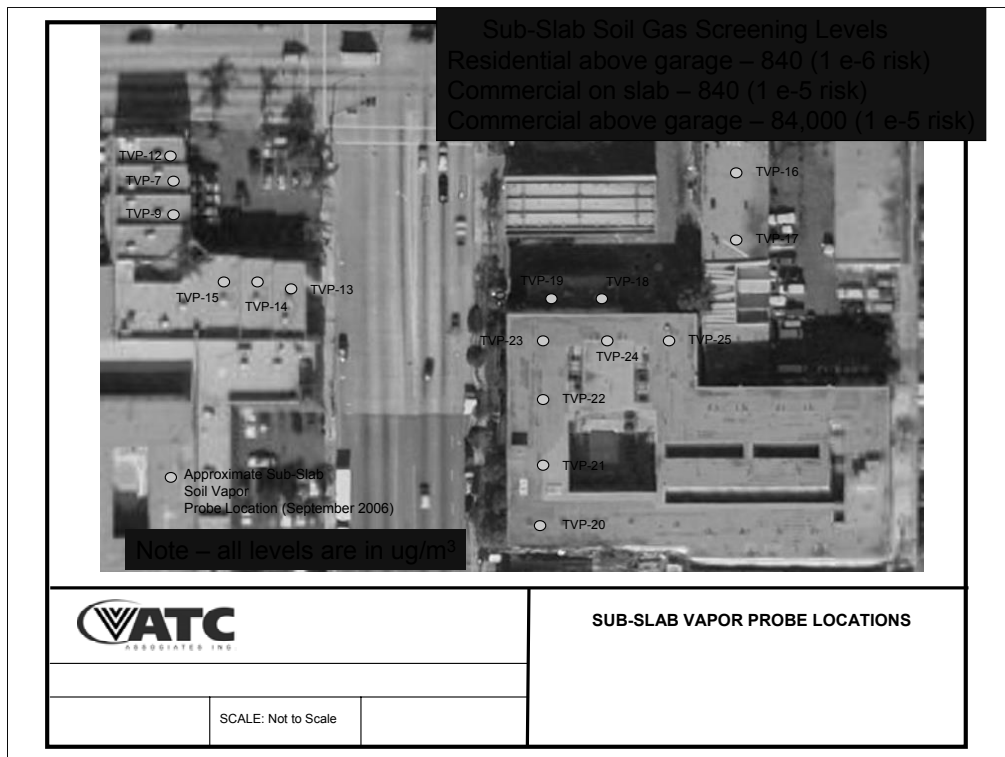
For the on-site store, ensure you have calculated the proper risk level. Collect samples around the store just below the pavement or sub-slab. If values exceed regulatory levels, collect radon to get a slab-specific alpha factor and measure the ventilation rate in the store since it will be much higher than regulatory defaults.

VI Case History #2

This site was a former gasoline station in an urban location. Soil contamination was left behind in the area of the former tank pit. The area of contamination was now paved over and used for parking for a neighboring strip mall. There were three potential receptors:

- 1) Slab-on-grade commercial businesses in the strip mall to the immediate west.
- 2) Commercial businesses above a parking garage to the immediate south.
- 3) Residential apts above a parking garage across the boulevard to the east.

The unique thing this scenario demonstrates is how various RBSLs were determined for the different receptors.



Map of the site and summarizing results.

Calculation of Commercial on Slab Sub-Slab Soil Vapor Risk Based Levels

Known

- CA Residential Human Health Screening Levels (CHHSL's) for Benzene = 0.084 µg/m³
- Exposure Time Difference for commercial facility = 5
- Factor for ventilation system in commercial building = 2
- Attenuation factor for concrete slab = 100

Given the above, a calculation for sub-slab benzene concentrations follows:

0.084 µg/m³ x 5 (for exposure time) x 2 (ventilation) x 100 (concrete attenuation factor) = **84 µg/m³ for 1 in 1 million risk level**

However, workplace regulated risk level (Prop 65) is 1 in 100,000, hence RBSL is **840 µg/m³ for 1 in 100,000 risk level**

Calculation of Commercial Above Garage Sub-Slab Soil Vapor Risk Based Levels

Known

- CA Residential Human Health Screening Levels (CHHSL's) for Benzene = 0.084 µg/m³
- Attenuation factor for floor concrete slab = 100
- Attenuation factor for ceiling concrete slab = 100
- Exposure Time Difference for commercial facility = 5
- Factor for ventilation system in commercial building = 2

Given the above, a calculation for sub-slab benzene concentrations follows:

0.084 µg/m³ x 100 (floor attenuation factor) x 100 (ceiling attenuation factor) x 5 (exposure time) x 2 (ventilation rate) = **8400 µg/m³ for 1 in 1 million risk level or 84,000 µg/m³ for 1 in 100,000 risk level**

Note: This RBSL is conservative as it ignores air exchange within the garage (likely a factor of 10)

Calculation of Residential Above Garage Sub-Slab Soil Vapor Risk Based Levels

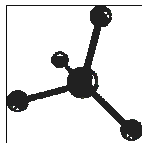
Known

- CA Residential Human Health Screening Levels (CHHSL's) for Benzene = 0.084 $\mu\text{g}/\text{m}^3$
- Attenuation factor for floor concrete slab = 100
- Attenuation factor for ceiling concrete slab = 100

Given the above, a calculation for sub-slab benzene concentrations follows:

$0.084 \mu\text{g}/\text{m}^3 \times 100$ (floor attenuation factor) $\times 100$ (ceiling attenuation factor) =
840 $\mu\text{g}/\text{m}^3$ for 1 in 1 million risk level

Note: This RBSL is conservative as it ignores air exchange within the garage (likely a factor of 10)



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